"A semi-conductor device and a method for varying current density in an active region of a junction of the semi-conductor device"

The present invention relates to a semi-conductor device, and in particular, though not limited to an optical semi-conductor device, for example, a semi-conductor laser device in which the current density in an active region of a junction is varied spatially in the active region. The invention also relates to a method for varying the current density spatially in the active region of the junction of the semi-conductor device.

Semi-conductor lasers, in particular, diffraction-limited high-brightness laser devices are suitable for a wide range of applications, for example, free space communication, and pumping of fibre lasers and amplifiers. Wide stripe semi-conductor lasers with relatively broad current stripes, for example, current stripes of the order of 100 micrometres or more tend to be transversely unstable, and suffer from filamentation and transverse mode beating. Insertion of mode filters, for example, cavity spoilers or saturable absorbers or other mode selective gain or loss means into such devices tend to enhance the modal performance by discriminating against higher order modes.

In relatively large area devices, both lasers and amplifiers, the current density, which through material interactions generates the carrier density, tends to increase along the edges of the gain region. This in general, is a feature of both flared and non-flared (broad area) devices. It is believed that the reason for the increase in current density along the edges of the active region is due to the shape of the transverse mode profile which results in relatively small field intensities at the longitudinal edges of the active region. The relatively small field intensity at the longitudinal edges of the active region is unable to saturate the gain, which in turn grows to relatively large values. These relatively large values of current density along the edges of the gain regions decrease the stability of the device, and thereby, the quality of the far-field.

It is desirable in many cases in semi-conductor electronic and optical devices to control the spatial distribution of electric current density conducted through such devices. It is known that current distribution though such devices can be controlled by locating multiple contacts on the device with different voltages applied to various

of the contacts. However, this requires the generation of many voltage levels for applying to the respective contacts, and also the provision of many connections to the various contacts. This is unsatisfactory in integrated circuit technology. It is also known that current distribution may be varied by localised ion implantation into the semi-conductor material for altering the conductive properties of the material. However, this can lead to other problems and disadvantages with the semi-conductor device.

There is therefore a need for an electronic or optical semi-conductor device which allows the current density distribution to be controlled without the disadvantages and problems of prior art techniques. Indeed, there is a need for a semi-conductor device in which the current density profile of an active region of a junction in the semi-conductor material of the device can be controlled. There is also a need for a method for varying the spatial distribution current density in an active region of a junction of a semi-conductor device.

The present invention is directed towards providing such an electronic and/or optical semi-conductor device, and a method for varying the spatial distribution current density in an active region of a junction of a semi-conductor device.

According to the invention there is provided a semi-conductor device comprising a semi-conductor medium which defines a junction, a first electrical contact and a second electrical contact, the respective electrical contacts being located spaced-apart from each other on the semi-conductor medium and in electrical contact with the semi-conductor medium for pumping current through the junction for forming an active region in the junction, wherein at least one of the first and second electrical contacts defines an outline area on the semi-conductor medium for determining the shape and area of the active region, and the at least one of the first and second electrical contacts forms an actual contact area or areas in which that one of the first and second electrical contacts is in actual electrical contact with the semi-conductor medium, and defines non-contact areas within the outline area in which no electrical contact takes place between that one of the first and second contacts and the semi-conductor medium, and the ratio of the actual contact area to the non-contact area

varies within the outline area for varying the current density spatially in the active region.

In one embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is varied as a function of the desired variation in the current density in the active region.

In another embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is varied in proportion to the desired variation in current density in the active region.

In a further embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is varied in a direction in which the current density is to be varied in the active region.

Preferably, the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is progressively varied for progressively varying the current density in the active region.

In one embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is varied in a transverse direction across the active region relative to the longitudinal direction of the active region for varying the current density transversely across the active region.

Advantageously, the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is progressively reduced towards opposite side edges of the active region which extend in a generally longitudinal direction relative to the active region for progressively reducing the current density in the active region towards the respective side edges.

In another embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is progressively reduced towards opposite side edges of the active region which

diverge away from each other in a generally longitudinal direction relative to the active region for progressively reducing the current density in the active region towards the respective diverging side edges.

In a further embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is varied in a direction longitudinally relative to the longitudinal direction of the active region.

In another embodiment of the invention the ratio of the actual contact area of the or each of the first and second electrical contacts is varied in directions both transversely and longitudinally relative to the active region.

In one embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is arranged in a direction generally transversely of the direction in which the ratio of the actual contact area to the non-contact area is varying for maintaining the current density in the active region substantially constant along lines of constant current density which extend in a direction generally transversely of the direction in which the ratio of the actual contact area to the non-contact area is being varied.

Preferably, the shape and area of the non-contact areas is such that the current density in areas of the active region which correspond to the non-contact areas is greater than zero.

In one embodiment of the invention the shape and area of the non-contact areas is such as to avoid induced grating effects in the profile of the current density in the active region.

In another embodiment of the invention the shape and area of the non-contact areas is such as to avoid induced grating effects in the profile of the current density in the active region in the direction transversely of the direction in which the current density is being varied.

Alternatively, the shape and the area of the non-contact areas is such as to induce predetermined grating effects in the active region.

In one embodiment of the invention the or each of the first and second electrical contacts comprises a main electrical contact and a plurality of spaced-apart secondary electrical contacts adapted to be electrically connected to the main contact, the main electrical contact and the secondary contacts together forming the actual contact area and defining the non-contact areas therebetween, and preferably, the secondary electrical contacts are electrically connected to the main contact.

In one embodiment of the invention the secondary contacts are provided by a plurality of elongated spaced-apart substantially parallel finger contacts extending from the main contact. Preferably, the finger contacts forming the secondary contacts taper from their respective proximal ends to their distal ends.

Advantageously, the main contact extends substantially longitudinally relative to the active region, and the secondary contacts extend transversely from the main contact in a direction generally transversely of the active region.

In an alternative embodiment of the invention the or each of the first and second electrical contacts comprises a single contact which forms the actual contact area, the single contact having a plurality of openings therethrough which form the non-contact areas.

In one embodiment of the invention the junction defined by the semi-conductor medium is a p-n junction.

Preferably, the first and second electrical contacts are located on respective opposite surfaces of the semi-conductor device for pumping the current through the active region of the junction.

In one embodiment of the invention the semi-conductor device is an optical semi-conductor device, the longitudinal direction of the active region being defined by the direction of light propagation in the active region.

In another embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is varied for inducing a current density profile in the active region which substantially coincides with the desired light intensity profile in the active region.

In a further embodiment of the invention the ratio of the actual contact area to the non-contact area of the or each of the first and second electrical contacts is varied transversely across the direction of light propagation in the active region for inducing a current density in the active region, the transverse profile of which substantially coincides with the desired transverse profile of light intensity at the corresponding location of the active region.

In one embodiment of the invention the first electrical contact defines the outline area.

In another embodiment of the invention the first electrical contact defines the actual contact area.

In a further embodiment of the invention the second electrical contact defines the outline area.

In a still further embodiment of the invention the second electrical contact defines the actual contact area.

Additionally, the invention provides a method for spatially varying the current density in an active region of a junction defined by a semi-conductor medium of a semi-conductor device, the method comprising placing a first electrical contact and a second electrical contact at spaced apart locations from each other on the the semi-conductor medium, and in electrical contact with the semi-conductor medium for pumping current through the junction for forming the active region, wherein at least

one of the first and second electrical contacts defines an outline area on the semi-conductor medium for determining the shape and area of the active region, and the at least one of the first and second electrical contacts forms an actual contact area or areas in which that one of the first and second electrical contacts is in actual electrical contact with the semi-conductor medium, and defines non-contact areas within the outline area in which no electrical contact takes place between that one of the first and second contacts and the semi-conductor medium, and the ratio of the actual contact area to the non-contact area varies within the outline area for varying the current density spatially in the active region.

The invention will be more clearly understood from the following description of some preferred embodiments thereof which are given by way of example only with reference to the accompanying drawings, in which:

Fig. 1 is a perspective view of an optical semi-conductor laser device according to the invention,

Fig. 2 is a graphical representation of a transverse profiles of current density and light intensity level in the active region of the optical semi-conductor device of Fig. 1,

Fig. 3 is a plan view of a portion of the device of Fig. 1,

Fig. 4 is an enlarged plan view of a part of the portion of Fig. 3,

Fig. 5 is a plan view of a portion of an optical semi-conductor laser device according to another embodiment of the invention,

Fig. 6 is a graphical representation of a transverse profile of current density in the active region of the device of Fig. 5,

Fig. 7 is a plan view of a portion of an optical semi-conductor laser device according to another embodiment of the invention,

Fig. 8 is a graphical representation of a transverse profile of current density in the active region of the device of Fig. 7,

Fig. 9 is a plan view of a portion of an optical semi-conductor laser device according to a further embodiment of the invention,

Fig. 10 is a graphical representation of a transverse profile of current density in the active region of the device of Fig. 9,

Fig. 11 is a plan view of a semi-conductor laser device according to another embodiment of the invention, and

Fig. 12 is a graphical representation of transverse profiles of current density in the active region of the device of Fig. 11.

Referring to the drawings and initially to Figs. 1 to 4 there is illustrated an optical semi-conductor device, in this embodiment of the invention a broad area laser device indicated generally by the reference numeral 1. The laser device 1 comprises a semi-conductor medium 2 formed by a p-type layer 3 and an n-type layer 4 which defines a p-n junction 5. A pair of electrical contacts, namely, a first electrical contact 6 and a second electrical contact 7 are located at opposite surfaces of the medium 2, namely, the first contact 6 is located on an upper surface 8 of the p-type layer 3, while the second contact 7 is located on a lower surface 9 of the n-type layer 4. The first and second contacts 6 and 7 are in electrical contact with the respective layers 3 and 4 through the surfaces 8 and 9, respectively, for pumping current through the p-n junction 5 for developing an active region 10 at the p-n junction 5 in which light is propagated in a direction parallel to a central longitudinal axis 11 of the active region 10. The second contact 7 extends over and is in electrical contact with the entire lower surface 9 of the medium 2.

The first contact 6 defines an outline area on the upper surface 8 which is indicated by the area bounded by the broken lines 12, which in turn, determines the shape and the area in plan view of the active region 10 in the p-n junction 5, and corresponds to the area of the active region 10. The first contact 6 is also shaped for varying the

spatial current density in the active region 10. In this embodiment of the invention the first contact 6 is shaped for varying the current density profile transversely across the active region 10 in the direction of the arrows A and B for avoiding regions of unsaturated gain adjacent respective opposite longitudinal edge regions adjacent longitudinal side edges 13 and 14 of the active region 10. In other words, the current density is varied in the active region 10 in a direction transversely of the direction of light propagation in the active region 10 and transversely of the central longitudinal axis 11.

In this embodiment of the invention, the first contact 6 comprises a main contact 15 which extends longitudinally along and parallel to central longitudinal axis 11 of the active region 10 in the direction of light propagation. A plurality of spaced apart secondary contacts formed by finger contacts 16 extend transversely from and are electrically connected to the main contact 15. The main contact 15 and the finger contacts 16 are in actual electrical contact with the surface 8 of the p-type layer 3, and thus form an actual contact area 17 on the upper surface 8 through which current is pumped through the upper surface 8 into the p-type layer 3. As can be seen the actual contact area 17 is entirely within the outline area 12 which is defined by distal ends 18 of the finger contacts 16. The main contact 15 and the secondary contacts 16 define non-contact areas 21 which lie within the outline area 12, and within which no electrical contact takes place between the first contact 6 and the upper surface 8. The finger contacts 16 taper outwardly from their respective proximal ends 19 to their respective distal ends 18, thereby progressively reducing the ratio of the actual contact area 17 formed by the finger contacts 16 to the non-contact area 21 defined by the finger contacts 16 in the directions of the arrows A and B towards the distal ends 18 of the finger contacts 16 for progressively reducing the current density in the active region 10 towards the side edges 13 and 14.

The shape and the area of the non-contact areas 21 is such as to avoid grating effects in the longitudinal direction parallel to the longitudinal axis 11 in the active region 10. In particular the spacing between adjacent side edges 20 of adjacent finger contacts 16 in a direction parallel to the longitudinal axis 11 is chosen to take account of the lateral diffusion characteristics of the p-type layer 3 and the distance from the active region 10 to the upper surface 8 for maintaining the current density in

the active region 10 constant along lines 22 of constant current density extending parallel to the longitudinal axis 11, thus avoiding any grating effects.

The laser device 1 may be formed by any suitable forming process, for example, an integrated circuit forming process or otherwise. Typically, in an integrated circuit forming process, the first electrical contact 6 will be deposited by a metal deposition and lithography stage in the forming process. Typically, the main contact 15 and the finger contacts 16 of the first contact 6 will be simultaneously formed in a metal deposition process.

Referring to Fig. 2 a plot of the current density profile transversely across the active region 10 from the side edge 13 to the side edge 14 is illustrated by the full line curve 25. The transverse profile of the light intensity of the laser light generated in the active region 10 across the active region 10 from the side edge 13 to the side edge 14 is illustrated by the broken line curve 26 in Fig. 2, and substantially coincides with the current density profile curve 25. Because the current density profile curve 26 substantially coincides with the light intensity profile curve 25 across the active region 10, unsaturated gain near the side edges 13 and 14 of the active region 10 is virtually entirely avoided. This is achieved by virtue of the fact that the ratio of the actual contact area 17 to the non-contact area 21 is progressively reduced in the direction in which the current density in the active region 10 is to be progressively reduced, and furthermore, is reduced in approximate proportion to the desired reduction in the current density.

The current density through the p-type layer 3, and in turn, through the active region 10 is reduced in the direction of the arrows A and B from positions substantially corresponding to the proximal ends 19 to the distal ends 18 of the finger contacts 16. The current density in the p-type layer 3 adjacent the upper surface 8 is not constant, however the current travelling from the finger contacts 16 through the p-type layer 3 diffuses laterally before reaching the active region 10. The amount of lateral diffusion depends on the thickness of the p-type layer 3 between the active region 10 and the first contact 6, the lateral diffusion characteristics of the p-type layer 3 which is a function of the doping concentration in the p-type layer 3 and the external bias between the first and second contacts 6 and 7. Therefore, by

appropriately reducing the ratio of the actual contact area 17 to the non-contact area 21, and by matching the shape and the area of the non-contact area 21 with these characteristics of the p-type layer 3, the desired transverse current density profile in the active region 10 can be achieved without any grating effects for eliminating saturated gain in the regions along the side edges 13 and 14. Additionally, by choosing the shape and the area of the non-contact areas 21, and in particular the spacing between adjacent edges 20 of adjacent finger contacts 16 with the characteristics of the p-type layer 3, namely, the thickness of the p-type layer 3, the lateral diffusion characteristics, and the external bias between the first and second contact 6 and 7, the current density in the active region 10 can be maintained constant along the lines 22 of constant current density which in this embodiment of the invention extend parallel to the central longitudinal axis 11 thereby avoiding induced grating effects in the active region 10. Such induced grating effects would scatter light out of the active region 10, and this, as discussed is achieved by controlling the spacing between the adjacent edges 20 of the adjacent finger contacts 16 so that the current pumped from adjacent finger contacts 16 will combine in the active region 10 due to lateral diffusion.

However, such grating effect in the longitudinal direction of light propagation may be desirable in certain implementations of the semi-conductor device 1, and in which case this would be achieved by also varying the ratio of the actual contact area 17 to the non-contact area 21 within the outline area 12 of the first contact 6 in the direction of light propagation.

In use, a voltage is applied across the first and second contacts 6 and 7, thereby pumping a current through the p-n junction 5 for forming the active region 10. The transverse profile of current density and the light intensity across the active region 10 is as illustrated in Fig. 2.

The advantages of the invention are many. A particularly important advantage of the invention is achieved by virtue of the fact that the transverse current density profile across the active region 10 is controlled by the ratio of the actual contact area 17 to the non-contact area 21 of the first contact 6. Thus, the current density across the active region 10 can be controlled without the need for space dependent doping of

the semi-conductor medium 2, and without the need for any other external or internal means for controlling current density. By controlling the current density across the active region 10 unsaturated gain near the longitudinal side edges of the active region is avoided. A particularly important advantage of the invention is that since the current density is controlled by altering the ratio of the contact area formed by the first contact 6 to the non-contact area defined by the first contact 6, the upper contact 6 can be maintained throughout at the same voltage. In other words, one single electrical connection to the first contact 6 is all that is required, since the main contact 15 and the finger contacts 16 are electrically connected to each other.

Referring now to Figs. 5 and 6 there is illustrated a first contact 30 for applying to an upper surface of a semi-conductor laser device (not shown) according to another embodiment of the invention. The first contact 30 is substantially similar to the first contact 6 of the laser device 1, and similar components are identified by the same reference numerals. The main difference between the first contact 30 and the first contact 6 is that the finger contacts 16 do not taper from their proximal ends 19 to their distal ends 18. This simplifies the lithographic requirements in the forming process.

Fig. 6 illustrates the transverse profile of the current density which is developed across the active region of the p-n junction of the semi-conductor medium of this laser device between the opposite longitudinal side edges which correspond to the opposite side edges 13 and 14 of the active region 10 of the laser device 1.

Fig. 7 illustrates a first contact 40 of a semi-conductor laser device (not shown) according to another embodiment of the invention, the first contact 40 is substantially similar to the first contact 6 of the laser device 1, and similar components are identified by the same reference numerals. The finger contacts 16 in this embodiment of the invention taper to points at their distal ends 18, and the rate of tapering from the proximal ends 19 to the distal ends 18 of the finger contacts 16 is significantly greater than that of the finger contacts 16 of the first contact 6 of the laser device 1.

Fig. 8 illustrates the transverse current density profile developed by the first contact 40 across an active region of this laser diode. The width of the upper flat region of the current density profile corresponds to the width of the main contact 15, and may correspondingly be varied.

Fig. 9 illustrates a first contact 50 for a semi-conductor laser device (not shown) according to a still further embodiment of the invention. In this embodiment of the invention the first contact 50 comprises a longitudinally extending central region 51 and a pair of side regions 52. A plurality of through openings, namely, holes 53 of similar diameter extend through the side regions 52 and form non-contact areas 21, while the central region 51 and the side regions 52 with the exception of the holes 53 form actual contact areas 17. The ratio of the actual contact area 17 to the non-contact areas 21 is progressively reduced towards respective longitudinally extending side edges 54 of the first contact 50 by progressively increasing the number of holes 53 per unit area in the direction of the arrows A and B towards the side edges 54.

Fig. 10 illustrates the transverse current density profile developed across an active region between opposite edges thereof which correspond to the edges 54 of the first contact 50.

Fig. 11 illustrates a plan view of a semi-conductor device, in this embodiment of the invention a flared laser device 60. The laser device 60 is substantially similar to the laser device 1 and similar components are identified by the same reference numerals. The laser device 60 comprises a semi-conductor medium 2 having an upper p-layer 3 and a lower n-type layer (not shown) which together define a p-n junction, similar to the p-n junction 5. A second contact (not shown) extends over a lower surface (also not shown) of the n-type layer similar to that of the laser device 1. The first contact 6, in this embodiment of the invention defines a flared outline area 12 which defines a correspondingly shaped flared active region (not shown) in the p-n junction. The first contact 6 comprises a central main contact 15, and a plurality of secondary finger contacts 16 extending from the main contact 15. The finger contact 16 taper from their proximal ends 19 to their distal ends 18 which define side edges 61 of the flared outline area 12. The flared side edges 61 diverge

from each other in a direction parallel to the longitudinal axis 11. The non-contact areas 21 are defined between the main contact 15 and the finger contacts 16 within the outline area 12. In this embodiment of the invention because the outline area 12 is flared the lines of constant current density 22 do not extend parallel to the central axis 11 but tend to approximately follow the contour of the side edges 61.

Fig. 12 illustrates transverse profiles of the current density across the active region of the laser device 60 at sections C, D, E and F along the longitudinal axis 11.

It is envisaged that in the case of the first contact 50 illustrated in Fig. 9 the ratio of the actual contact area to the non-contact area may be varied by varying the size of the holes, instead of or as well as varying the number of holes per unit area.

It is also envisaged that the first contact may be provided as a plurality of discrete contacts which would be electrically connected together. The ratio of the actual contact area to the non-contact area would then be varied by appropriately varying the number of discrete contacts per unit area and/or by varying the area of the discrete contacts. A central area of the first contact may be formed by a single contact or by a plurality of discrete contacts, and when the central area is provided by a number of discrete contacts, assuming peak current density is to be formed in the active region corresponding to the central area of the first contact, the discrete contacts would be located relatively closely together, in other words, a high number of discrete contacts per unit area would be provided, and/or the area of the discrete contacts would be greater than those towards the longitudinal side edges of the first contact.

While the first contacts have been described as being shaped for developing a current density profile across the active region of a semi-conductor laser device which increases progressively from the respective opposite side edges to a central peak value, it will be appreciated that the first contacts may be shaped to develop any other desired current density profiles.

While the semi-conductor device has been described in all the embodiments of the invention as being a laser device, the semi-conductor device could be any other type

of device, for example, a diode, a transistor, a field effect transistor or the like, in which it is desired to develop a varying current density profile in the active region of the junction, be it a p-n junction or otherwise. Furthermore, the laser device could be a laser amplifier.

While in the embodiments of the invention described the upper first contact has been described as being shaped to develop the varying current density, it will be readily apparent to those skilled in the art that the lower second contact could be shaped or profiled to develop the desired current density profile. Indeed, in certain cases, it may be desirable to shape both the first and second contacts to form the desired current density profile.

The semi-conductor medium instead of being a two layer medium may be a multi-layer medium, and may have a number of p-type layers and n-type layers.

It will also be appreciated that while the laser devices have been described with the first contacts shaped to avoid induced grating effects, the first and/or second contacts may be shaped to induce predetermined grating effects where such grating effects are desired.